Construction activity

Construction work of the Laser R&D blocks A,B & C and of the Accelerator Support Technology Building is nearly over. Construction work of the canteen building and an overhead water tank with distribution lines etc. is in an advanced stage of completion. Central A/C plant has been commissioned. Two sump wells, each of four lakhs litres capacity, have been put into operation.

All the 399 houses of various categories sanctioned under the seventh plan have been completed. Construction of 162 houses out of the 184 houses sanctioned under the eighth plan is in progress.

Synchrotron Radiation Source INDUS - 2: Design Features

Charged particles emit electromagnetic radiation when they are accelerated, and thus this radiation is observed when electrons are forced to follow a curved path in a magnetic field. In synchrotrons and storage rings, electron bunches at relativistic energies are forced to traverse curved paths by the bending magnets. The radiation emitted during bending, referred to as synchrotron radiation, has several important characteristics including high intensity, broad spectral range, natural collimation, high polarization, pulsed time structure and small source size. Any or a combination of these properties makes synchrotron radiation an important scientific tool for a wide variety of scientific and technological applications.

A synchrotron radiation source (now also simply called synchrotron source) is an electron storage ring designed and operated specifically for the production of synchrotron radiation. However, the first generation sources were high energy particle accelerators built for particle physics studies on which synchrotron radiation users were considered parasites. The second generation sources are electron storage rings such as SOR (Japan), SRS (UK) and NSLS (USA) built specifically for production of synchrotron radiation. In these rings which are presently operational and also extensively used, the major sources of radiation are bending magnets. The radiation from a bending magnet has a continuous spectrum with wavelengths ranging from infrared to x-rays. (This spectrum is characterized by a wavelength called critical wavelength. In the power spectrum, half of radiation power is emitted below this wavelength and half above this wavelength.) The third generation sources are more powerful sources in which radiation also comes from insertion devices. Several such sources are presently under construction and some including SUPERACO (France), ALS (USA) and ESRF (France) are already operational. The insertion devices used in these sources are wigglers and undulators. Both of these devices provide transverse alternating magnetic field along the straight path of electrons which cause them to periodically accelerate inwards and outwards giving rise to a series of local radiation sources. The radiation produced from wigglers have characteristics similar to bending magnet radiation with the difference that the spectrum of radiation is shifted and the intensity is enhanced in proportion to the number of poles. In undulators, electrons undergo feeble deflections; the radiation from these have sharp peaks at certain wavelengths. The intensity of the radiation at these wavelengths becomes much higher and increases as the square of the number of undulator periods. In VUV and x-ray range, second and third generation sources are much more powerful compared to conventional sources.

The Centre for Advanced Technology (CAT) is constructing two synchrotron radiation sources; INDUS-1, a 450 MeV electron storage ring for VUV radiation and INDUS-2, a 2 GeV storage ring for x-rays. The design of INDUS-1 has been discussed in the December 1988 issue of the CAT Newsletter. Presently, INDUS-1 is in an advanced stage of construction, and the construction of INDUS-2 will start soon. In this article, our objective is to discuss basic design features of INDUS-2 including the characteristics of x-rays which will be available from this source. In order that a reader is able to appreciate the capabilities of such a source, a brief description of some applications of x-rays from synchrotron radiation sources is given.

X-rays, because of having wavelengths ranging from a fraction to few multiples of an Angstrom (and photon energy of few keV) are an important tool for learning about atomic positions, bond lengths, binding energies and chemical composition. For providing such information, x-rays are used in several disciplines e.g. material science, chemistry, molecular biology and geology. Most useful properties of x-rays from synchrotron radiation sources are intensity or flux (number of photons emitted per second per mrad in a given spectral bandwidth) and brightness (number of photons emitted per unit source area per unit solid angle in a given bandwidth) which are several orders of magnitude higher than conventional x-ray sources. The high intensity enables experiments to be performed incredibly rapidly, while high brightness enables study of extremely small samples with a high spectral or energy

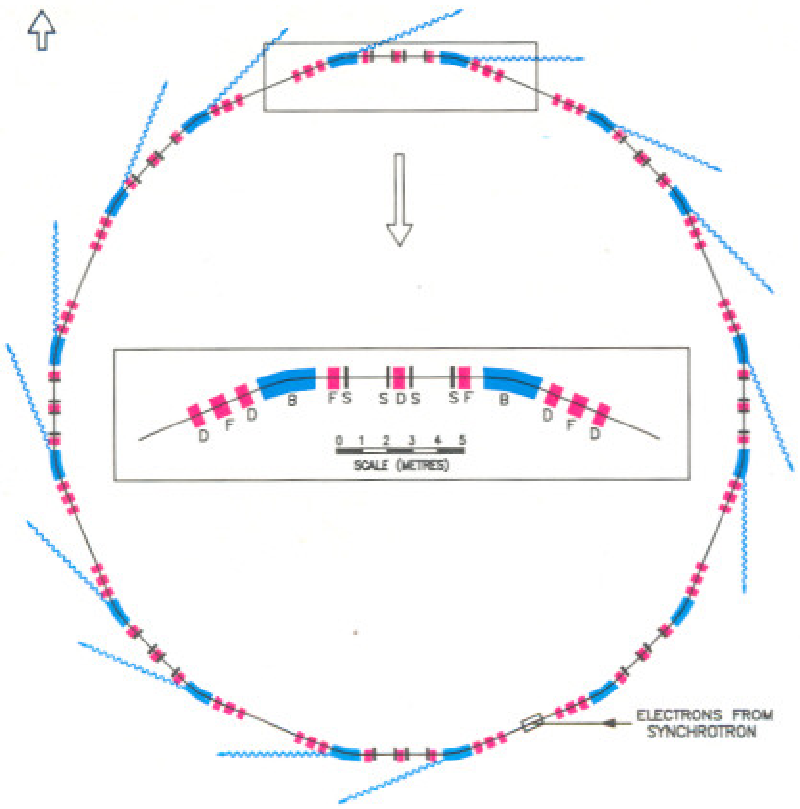

Fig. 1: Synchrotron radiation source INDUS-2 is shown with 8 unit cells. Inset highlights a unit cell with bending magnets (B), quadrupoles (F & D) and sextupoles (S).

resolution. In fact, several experiments, which were hitherto considered impossible because of inadequate resolution or long measurement times, can now be performed using synchrotron radiation. A few examples are discussed below.

Synchrotron radiation is very widely used in protein crystallography because of its high intensity which enables collection of high quality data much more rapidly and generally to a much higher resolution than with conventional sources. To take a diffraction pattern of a protein crystal which requires three weeks with a conventional source, requires only a second with a synchrotron radiation source. The tunability and pulsed time structure of synchrotron radiation are also important features for protein crystallography; these can be used to solve the phase problem without using additional samples. Synchrotron radiation is also widely used for EXAFS (Extended X-ray Absorption Fine Structure) studies which make use of the continuous spectrum of the radiation. Because of the high intensity of the radiation, the time required to perform an experiment is drastically reduced. EXAFS is now a powerful technique for determination of local atomic arrangements in complex systems, and in poorly crystallized and amorphous materials. Recently, it has also been used to study the behaviour of biological enzymes and catalysts. Due to the high flux, tunability and linear polarization of synchrotron radiation, the technique of x-ray fluorescence (XRF) spectroscopy is now capable of analyzing samples to sub-ppm levels and due to its high brightness spatial resolution down to few microns is possible. The availability of highly intense and nearly parallel x-rays of the required wavelength (~10Å) from synchrotron radiation sources has also benefitted the area of semiconductor technology. By using x-ray lithographic techniques, it is now possible to make integrated circuit chips with an element size less than 0.5 micron. By following a similar approach, efforts are being made to produce micromechanical components such as gears.

As already mentioned that flux and brightness are very important parameters for many applications, a synchrotron radiation source is therefore designed to provide radiation of high flux and high brightness. In addition, it should have a number of long straight sections to accommodate insertion devices which produce radiation of different characteristics. Third generation sources are designed taking all these factors into consideration. The same guidelines have also been followed while designing INDUS-2. In order to increase photon flux, the stored current in the accelerator should be as high as possible. There has not been much improvement in the current because of the problems of beam instabilities, ion trapping etc. which persist even now. However, the flux in the third generation rings have increased significantly with the use of wigglers and undulators. The major improvement made in the third generation sources is the enhancement of brightness by several orders of magnitude, this is achieved by reducing the electron beam emittance and by using long undulators.

A synchrotron or storage ring has various types of magnets viz. bending magnets, quadrupoles and sextupoles. Bending magnets are used to keep the electrons moving in a circular orbit, quadrupoles to keep the beam focussed in radial and vertical planes and sextupoles for correction of chromaticities discussed later in this article. These magnets are arranged in a periodic way and the circumference can be divided into many identical parts each having the same arrangement of magnets. Each part constitutes a unit cell and the arrangement of magnets in this cell defines the lattice of the accelerator. Further, electrons circulating in these accelerators make betatron oscillations in radial and vertical planes; the phase space area in each of these planes is defined by a constant, called beam emittance. The radial or horizontal emittance of the beam in a storage ring is determined by an equilibrium between the process of quantum excitation of betatron oscillations and that of radiation damping. The resultant emittance depends upon the magnetic lattice of the ring and varies quadratically with beam energy. However, in third generation sources a higher beam energy is preferred for several reasons which include minimizing the adverse effect of insertion devices on beam optics and production of shorter wavelengths with undulators. The vertical emittance is governed by the coupling between the horizontal and vertical motions and is usually a small fraction of the horizontal emittance. The horizontal emittance increases with insertion devices if the straight sections accommodating them do not have zero dispersion.

Parameters of INDUS-2

Energy	2 GeV
Current	300 mA
Bending field	1.2 T
Critical Wavelength, λ_c	3.88 Å (BM)
	0.93 Å (HFW)
	2.59 Å (MW)
Circumference	172.3 M
Typical tune point	9.2, 5.2
Beam emittance, ε_x	3.9×10^{-8} m.rad
ε_z	3.9×10^{-9} m.rad
Electron beam size and divergence	
at Centre of bending magnet, σ_x,σ_z	0.19, 0.20 mm
σ_x',σ_z'	0.28, 0.05 mrad
Centre of insertion section, σ_x,σ_z	0.65, 0.08 mm
σ_x',σ_z'	0.06, 0.05 mrad
Photon flux	9.6×10^{12} (BM)
	2.9×10^{13} (HFW)
	1.1×10^{14} (MW)
Brightness	9.3×10^{13} (BM)
	1.0×10^{14} (HFW)
	3.2×10^{14} (MW)
Bunch length	3.0 cm
Beam lifetime	24.0 Hours
Energy spread	7.2×10^{-4}
Revolution frequency	1.7402 MHz
RF cavity frequency	189.678 MHz
Harmonic number	109
Radiation power loss	76.3 kW (BM)
	7.6 kW (HFW)
	5.2 kW (MW)

BM : Bending Magnet
MW : Multipole Wiggler (1.8 T)
HFW : High Field Wiggler (5 T)
Brightness in Photons/sec/mm^2 /mrad^2 0.1% BW
Flux in Photons/sec/mrad horz./0.1% BW

The lattice for a synchrotron radiation source should be such that it provides a small beam emittance along with zero dispersion in the straight sections for insertion devices. To satisfy both these conditions several lattices have been developed but the most commonly used are Chasman Green (CG) and Triple Bend Achromat (TBA) lattices. The major difference between the two is that the former has two bending magnets in a unit cell, whereas the latter has three. The beam emittance decreases as the third power of the bending angle, therefore a large number of unit cells helps in reducing the beam emittance. In order to achieve a small emittance in these lattices, the beam has to be strongly focussed inside the bending magnets with the help of quadrupoles present in the cell. Since the beam has a small energy spread and the focussing strengths of quadrupoles vary with electron energy, a chromatic aberration similar to light optics (where glass lenses focus different colours differently) arises. The correction of the chromatic aberration (or chromaticity as it is called in the accelerator terminology) is essential to store high currents. The chromaticity is corrected by using sextupoles in the region of finite dispersion. Being nonlinear focussing lenses, sextupoles have an adverse effect on the machine i.e. they drastically reduce the dynamic aperture which is the stable area for beam motion. Increasing the number of unit cells reduces the dynamic aperture further because this increases the strengths of sextupoles. In addition, the number of cells is also governed by the number of straight sections required for insertion devices. The optimum number of cells is chosen by taking into consideration the number of straight sections required for insertion devices and the dynamic aperture requirements for beam injection and beam lifetime at injection and at peak energy . Obviously, if the number of cells is increased, the cirumference and the number of components will also increase and the cost of the machine will go up; therefore economics also plays a role in deciding the design.

Before coming to the lattice for INDUS-2, a comment on the comparison of CG with TBA is necessary. For a given circumference (with a given number of unit cells), the TBA lattice can give a much smaller beam emittance than the CG lattice because of the fact that the former has three bending magnets and the latter only two, but the disadvantage of the TBA is that the dynamic aperture becomes much smaller. An increase in the dynamic aperture is possible with the expansion of the unit cell and use of additional quadrupoles but this increases the beam emittance and makes the unit cell much longer. It is also possible to reduce the beam emittance in a CG lattice by modifying the achromat section; instead of one quadrupole, if a quadrupole triplet in the FDF (focussing defocussing focussing) configuration with an optimally large gap between F and D quadrupoles is used, a beam emittance comparable to a TBA lattice can be achieved along with a much higher dynamic aperture. Such a magnetic structure classified as an expanded Chasman Green lattice has been selected and optimized for INDUS-2.

The storage ring INDUS-2 consists of 8 unit cells each providing a 4.5 m long straight section. The magnetic structure of the storage ring INDUS-2 is shown in figure-1. Its unit cell has two 22.5° bending magnets, a triplet of quadrupoles for the control of dispersion in the achromat section, two quadrupole triplets for the adjustment of beam sizes in the long straight sections, and four sextupoles in the achromat section for the correction of chromaticities. An additional advantage of this lattice is that the two long gaps between the focussing and defocussing quadrupoles in the achromat section provide a lot of space for accommodating beam diagnostic and vacuum devices. The design parameters of the source are given in the table. The dynamic aperture with chromaticity correcting sextupoles is more than 30mm in the horizontal plane and 20mm in the vertical plane. This is adequate from the considerations of beam injection and beam lifetime. A similar structure with a gradient in bending magnets has been adopted for the synchrotron radiation source ELETTRA under construction at Trieste (Italy). Though the gradient has some beneficial effects on the beam optics, we have chosen normal parallel edged magnets to avoid fabricational problems associated with gradient magnets.

The injection energy for INDUS-2 is 700 MeV and the electron at this energy will be injected into it from the 700 MeV synchrotron which is also the injector for INDUS-1. The beam lifetime at 700 MeV, decided mainly by intrabeam scattering and single bunch instabilities, has been calculated to be 30 minutes which seems adequate to store a current of 300 mA. After injection at 700 MeV, the energy of the beam will be slowly raised to 2 GeV within a few minutes. The beam lifetime at 2 GeV is expected to be 24 hours which is mainly governed by Touschek scattering, assuming of course, that the beam circulates in an UHV environment having vacuum better than 10^{-9} mbar. An RF voltage of 1.5 MV is required to achieve this lifetime and this will be generated at the required frequency of 189.7 MHz by employing three RF cavities. Of the eight 4.5 m long straight sections, one will be used for beam injection and two for RF cavities and the remaining five for insertion devices. Presently, two wigglers are planned to be installed in the ring. The remaining three straight sections will remain unused for some time leaving some scope for further development of the machine based on the future radiation requirements of users, or on major breakthrough or development in the science and technology of insertion devices.

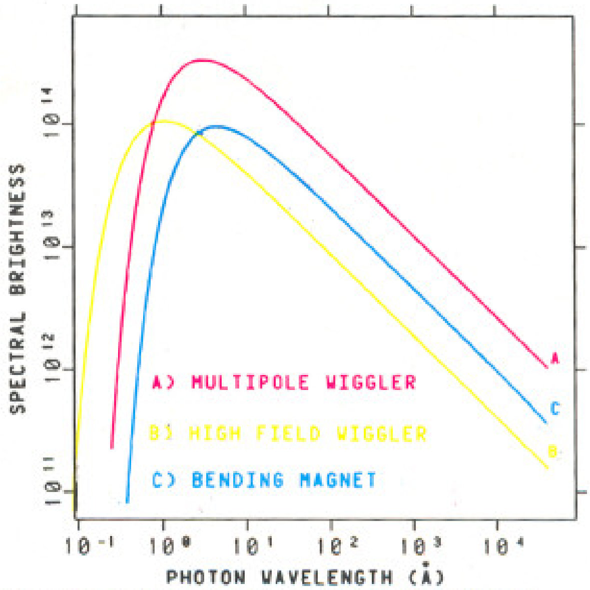

Fig. 2: Brightness as a function of wavelength for INDUS-2.

As an x-ray source, INDUS-2 is envisaged to provide radiation from bending magnets and wigglers. Its beam energy of 2 GeV is adequately high to produce powerful x-rays from these devices. The magnetic field in a bending magnet at 2 GeV will be 1.2 Tesla which will generate radiation of critical wavelength 3.9 Å. One wiggler will be an 11 pole electromagnet with a magnetic field of 1.8 Tesla. This will provide radiation of critical wavelength 2.6 Å and flux and brightness an order of magnitude higher than the bending magnets. The other wiggler will be a superconducting magnet with 5 poles and peak field of 5 Tesla. The critical wavelength of its radiation will be 0.9 Å and this device will provide a good flux and brightness even upto much shorter wavelengths say, 0.2 Å. The values of flux and brightness at the critical wavelengths are given in the table and the brightness plot for these devices is shown in figure-2. It is possible to operate INDUS-2 at any energy between 700 MeV and 2 GeV. At lower energies, the emittance of the ring will be much lower and it can be used to produce radiation of much higher brightness at longer wavelengths. The layout of the ring has been designed such that more than fifteen beam lines can be set up on it. The identification of beamlines for various studies has not yet been made but the studies for which these will be used include EXAFS, XANES, diffraction, X-ray topography, XRF, and photoemission.

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